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MEMORANDUM

SOME EFFECTS OF YAW DAMPING ON AIRPLANE MOTIONS AND VERTICAL-TAIL LOADS IN TURBULENT AIR

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SOME EFFECTS OF YAW DAMPING ON AIRPLANE MOTIONS AND VERTICAL-TAIL LOADS IN TURBULENT AIR

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SUMMARY

Results of analytical and flight studies are presented to indicate the effect of yaw damping on the airplane motions and the vertical-tail loads in rough air. The analytical studies indicate a rapid reduction in loads on the vertical tail as the damping is increased up to the point of damping the lateral motions to 1/2 amplitude in one cycle. Little reduction in load is obtained by increasing the lateral damping beyond that point. Flight measurements made in rough air at 5,000 and 35,000 feet on a large swept-wing bomber equipped with a yaw damper show that the yaw damper decreased the loads on the vertical tail by about 50 percent at 35,000 feet. The reduction in load at 5,000 feet was not nearly as great. Measurements of the pilot's ability to damp the lateral motions showed that the pilot could provide a significant amount of damping but that manual control was not as effective as a yaw damper in reducing the loads.

INTRODUCTION

The trend toward increased operating altitudes and the use of swept wings on newer transports contribute to a deterioration of lateral-directional damping. Because of the low damping, disturbances caused by turbulence result in large-amplitude oscillatory motions. Such oscillations are objectionable to the pilot and passengers and, in addition, produce sizable loads in the vertical-tail structure. The NASA has been conducting analytical and experimental studies to determine the effect of damping on the lateral motions of the airplane and on the vertical-tail loads in rough air. This paper presents some results of these studies to show the effect of damping on the motions and loads in rough air, and to indicate the reductions obtained by increasing the damping.

CALCULATIONS

Effect of Period and Damping

Calculations for the effect of period and damping on the loads on the vertical tail due to turbulence were made on the assumption that the only parameters of importance are the period and the damping of the lateral motions. A brief analysis indicated that, for most airplanes, other parameters can be neglected without too much loss in accuracy. On this basis, calculations were made for the ratio of the sideslip angle at the vertical tail to the gust angle, which is a measure of the load on the vertical tail.

The results of the calculations are shown by the three curves in figure 1. The ordinate values are the ratio of the root-mean-square sideslip angle at the vertical tail to the root-mean-square gust input angle. These values for three lateral frequencies are plotted against the damping parameter, which is the reciprocal of the number of cycles to damp the lateral motion to 1/2 amplitude. The lateral frequency is expressed in terms of the wavelength of the lateral oscillation in feet and is the product of the lateral period in seconds and the true airspeed in feet per second. The three frequencies shown cover the range for most transport airplanes.

The curves in figure 1 show that as the lateral damping of an airplane is increased, the loads on the vertical tail in rough air decrease rapidly until the damping parameter reaches a value of about 1 (that is, a damping of the lateral motion to 1/2 amplitude in one cycle). Little is gained by increasing the damping beyond this point. Figure 1 also indicates that a 2-to-1 change in the wavelength of the lateral motion has only a small effect on the vertical-tail loads.

Trend in Vertical-Tail Loadings of New Transports

The calculations presented in figure 1 can be used to indicate the trend in loads on the vertical tail surface in rough air for some of the newer transports. The symbols locate some representative transport airplanes on the curves according to the damping of the lateral motions under given operating conditions. The open circles represent three swept-wing jet airplanes without yaw dampers flying at about 35,000 feet. The solid circles are for the same airplanes and altitudes but with yaw dampers in operation. The diamonds show the damping at 10,000 to 15,000 feet for several unswept-wing piston-engine airplanes which have proved to be satisfactory in service.

A comparison of the ratios of sideslip angle to gust angle for the airplanes denoted by the symbols in figure 1 indicates the following results for flight at the same dynamic pressure and in the same intensity of turbulence: Swept-wing airplanes operating at 35,000 feet without yaw dampers can be expected to experience much higher vertical-tail loads than current transports operating at 10,000 to 15,000 feet. With yaw dampers in operation, however, the high-altitude airplanes can be expected to experience almost the same vertical-tail load as current transports.

FLIGHT TESTS

Effect of Yaw Dampers

Some time histories of measurements of the motions and vertical-tail loads experienced in rough air by a jet airplane which has a configuration generally similar to the new transports are shown in figures 2 and 3. Figure 2 shows time histories of the lateral gust velocity (expressed as the gust angle-of-attack changes at the vertical tail), the sideslip angle, the vertical-tail bending strains, and the rolling and yawing velocities of the airplane. These measurements were made at a Mach number of 0.6 at 35,000 feet. The yaw damper was not in operation during the run shown in figure 2 and the pilot was flying "hands-off" as much as possible. The time histories indicate that under these conditions the airplane experienced large rolling and yawing motions at the Dutch roll frequency of about 1 cycle in 5 or 6 seconds. An important point to note is that the amplitude of the sideslip angle is 3 or 4 times the amplitude of the gust input angle. Another point is that the measured tail strains closely follow the sideslip motions of the airplane, thereby indicating that most of the tail strains result from the motions of the airplane and very little from what might be considered the direct gust effect.

Figure 3 shows time histories of the same quantities measured in turbulence of about the same intensity and under similar flight conditions but with the yaw damper in operation. It is apparent from a comparison of figures 2 and 3 that the yaw damper reduces the amplitudes of both the lateral motions and the tail strains by a considerable amount.

The magnitude of this reduction in tail strain is shown in figure 4. Figure 4 shows the percentage of time the root bending strains of the vertical tail were above a given level in the tests of the swept-wing jet airplane at an altitude of 35,000 feet and a Mach number of 0.6 and at an altitude of 5,000 feet and a Mach number of 0.3. The two flight Mach numbers correspond to about the same dynamic pressure at both altitudes. The solid lines show the results for the runs with yaw damper off, and the dashed lines for yaw damper on.

It is obvious from a comparison of the curves in the left-hand plot of figure 4 that yaw damping reduces the magnitude of the loads considerably at high altitudes. This reduction is about 50 percent at 35,000 feet. At 5,000 feet, where the damping in yaw for the basic airplane is better, the benefit of yaw damping is much less, as shown in the right-hand plot of figure 4.

Yaw-Damping Effectiveness of a Pilot

So far the discussion has been concerned with the effect of yaw dampers in alleviating airplane motions and vertical-tail loads in rough air. One additional question of interest concerns the ability of a pilot to control the airplane in the event of damper failure.

In order to assess the effectiveness of the pilot in damping the Dutch roll motions of an airplane, flight tests have been made in turbulent air, first with the pilot flying essentially hands-off and then with the pilot controlling the lateral motions. Figure 5 summarizes the results of these tests.

The results in figure 5 indicate the percentage of time the sideslip angle and vertical-tail strains were above a given level. Tests without the yaw damper are indicated by solid lines; those with pilot control of the yawing motion, by long-dash lines; and those with yaw damper on, by short-dash lines. These tests were made at 21,000 feet at a Mach number of 0.6.

The results indicate that the damping provided by the pilot resulted in a significant reduction in the lateral motions of the airplane and the vertical-tail loads. This damping provided by the pilot, however, was not as great as that provided by the yaw damper. The pilot commented that the long-period oscillation can be readily damped out but that over a long time interval such constant control effort would become tiresome.

CONCLUSIONS

Analytical and flight studies of the effect of yaw damping on airplane motions and vertical-tail loads have resulted in the following conclusions:

1. Theoretical considerations indicate that little reduction in vertical-tail loads is obtained by increasing the damping beyond the point where the oscillations damp to 1/2 amplitude in one cycle.

2. Measurements on a large jet airplane in rough air at 35,000 feet have indicated that yaw-damper operation resulted in a 50-percent reduction in both aircraft motions and vertical-tail loads. At 5,000 feet, where lateral damping is better, benefits of the yaw damping are much less.

3. It would appear that a pilot may be able to provide sufficient damping in the event of failure of the yaw damper.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 5, 1958.

CALCULATED EFFECT OF DAMPING ON VERTICAL-TAIL LOADS

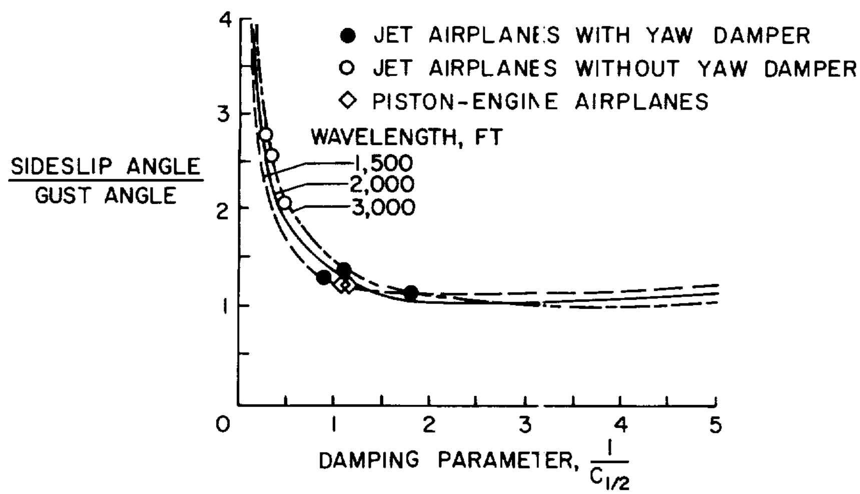

Figure 1

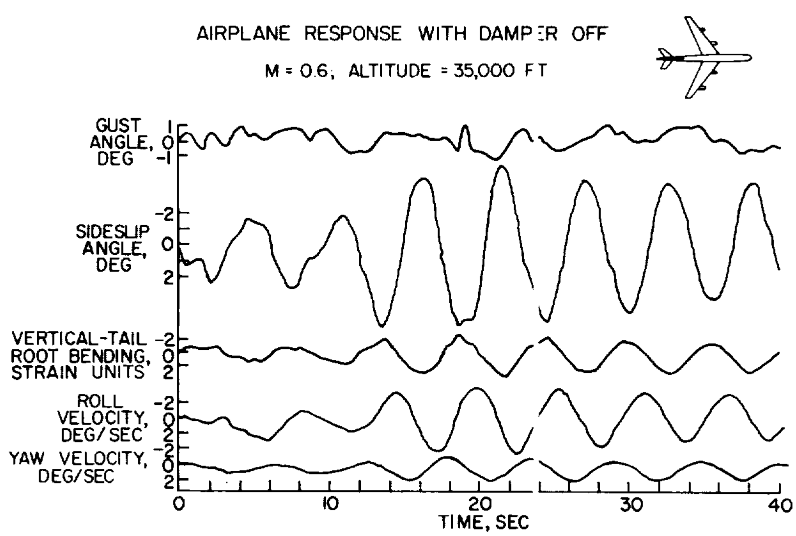

Figure 2

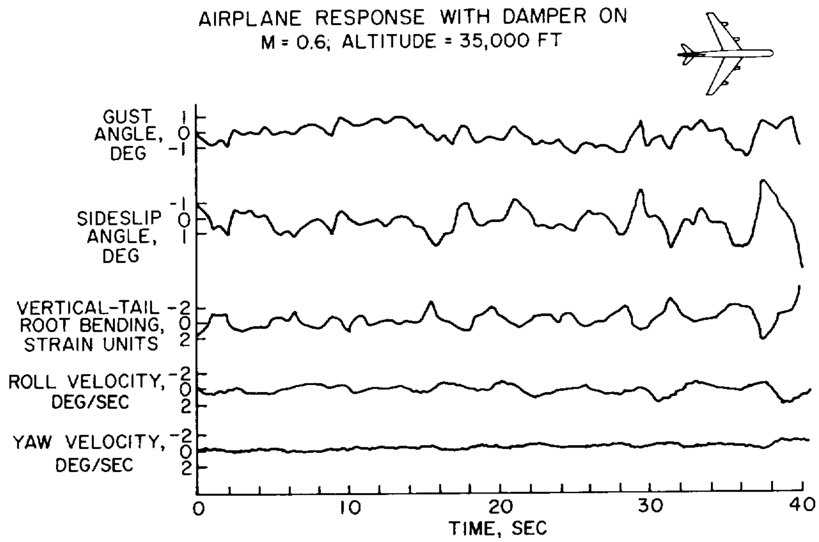

Figure 3

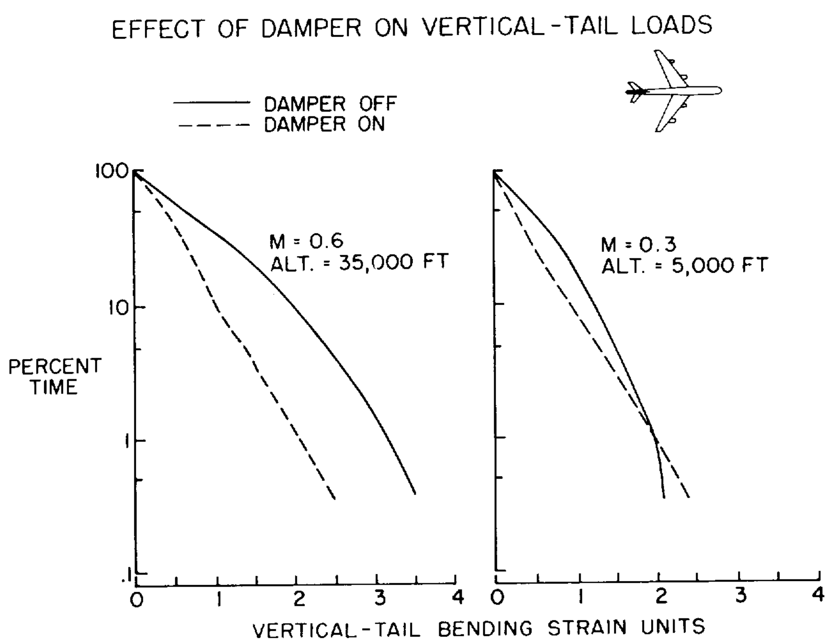

Figure 4

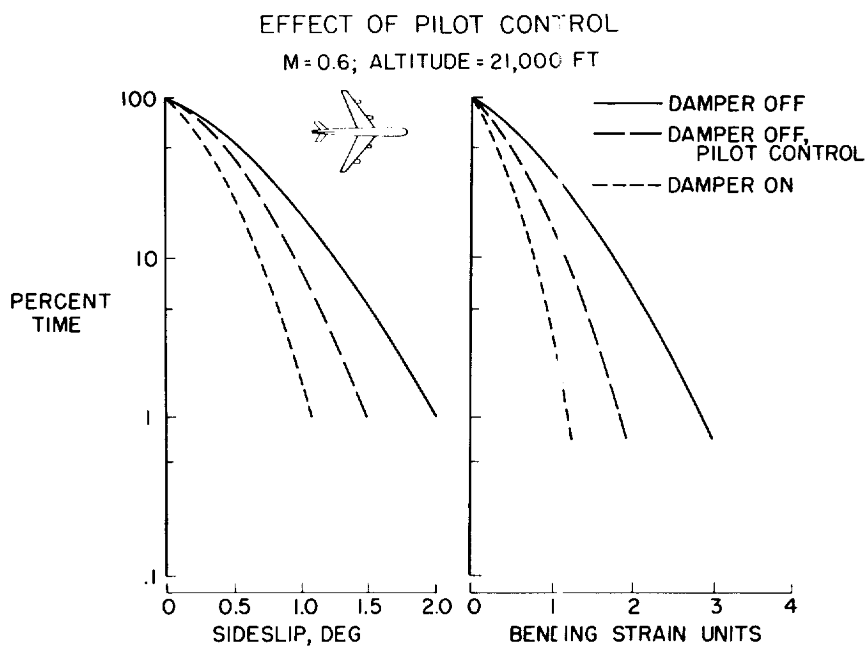
EFFECT OF PILOT CONTROL
M = 0.6; ALTITUDE = 21,000 FT
100
10
PERCENT
TIME
1
.1
0
0.5
1.0
1.5
2.0
SIDESLIP, DEG
0
1
2
3
4
BENDING STRAIN UNITS
DAMPER OFF
DAMPER OFF, PILOT CONTROL
DAMPER ON

Figure 5